REPORT 44

SWEEP

SOIL AND WATER

ENVIRONMENTAL

ENHANCEMENT PROGRAM

PAMPA

PROGRAMME D'AMELIORATION

DU MILIEU PEDOLOGIQUE

ET AQUATIQUE

Canada

Ontario

SWEEP

is a $30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.

PURPOSES

There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.

BACKGROUND

The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.

PAMPA

est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.

SES BUTS

Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.

SES GRANDES LIGNES

L'entente entre le Canada et les États-unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.

100-05263/

TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

COMPARISON OF PLANTERS AND FERTILIZER APPLICATION SYSTEMS FOR NO-TILL CORN

FINAL REPORT

March, 1992

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COMPARISON OF PLANTERS AND FERTILIZER APPLICATION SYSTEMS FOR NO-TILL CORN

FINAL REPORT

SWEEP-TED PROJECTS

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EXECUTIVE SUMMARY

A project was conducted in response to difficulties being encountered with conventional fertilizer placement systems for corn on no-till planters. To overcome these difficulties, farmers have made various modifications to planters and fertilizer application systems. This project evaluated three recent developments in fertilizer application systems: (1) a cross-slot planting system developed in New Zealand which results in less soil disturbance than other no-till planters and places fertilizer closer to the seed row than a conventional side band (5 cm to side and 5 cm below) (2) a strip-band fertilizer application system developed at Guelph which places fertilizer in two strips, one on either side of the row and about 2 cm below (3) a coulter-strip fertilizer application in which the fertilizer is deposited on the soil surface in front of a fluted coulter.

Experiments were conducted at two field sites in Huron Co. and Oxford Co. in 1990 and at three sites in 1991, one in each of Kent, Huron and Oxford Cos.

The specific objectives of the study were:

a) To compare the effectiveness of planting and fertilizer application using the cross-slot, strip-band and coulter-strip application systems.

b) To compare the cross-slot planter with a conventional planter under varying soil conditions.

At each site varying rates of fertilizer were applied based on the phosphorus required according to the OMAF soil test system. Plant samples were collected periodically during early growth stages to determine shoot growth and nutrient concentrations. Final yields were determined at maturity.

The strip band application did not increase early season dry matter or shoot P concentration compared to the side band. Final grain yields were somewhat greater at both sites in 1991 although the differences were not significant at P=0.05. A similar result was obtained in a previous study conducted in 1989. When the results of the two years were combined, the mean difference (380 kg ha^{-1}) was significant at P=0.08. There was no response to phosphorus at either site in 1990 so a comparison of application methods was not meaningful. It is concluded that the strip band is marginally superior to the

side band but the difference is not sufficient to justify the planter modifications required. Yield increases of a similar magnitude can be obtained by applying a small amount of fertilizer with the seed.

The coulter-strip fertilizer application system did not result in significant differences in early shoot growth or nutrient concentration compared to the side band using the same planter for both placements. Similarly there was no difference in grain yield. However, the experiments did not allow a good comparison of the coulter-strip system. In 1990 there was no response to fertilizer P so a comparison of placements is not meaningful. In 1991 the conditions for planting were not good so there was essentially no mixing of the fertilizer with the soil with the coulter strip system. The location and distribution of P determined in 1990 did indicate that the fertilizer was mixed only with the upper 2-3 cm of soil. This would not be expected to provide phosphorus to plants in the early growth stages.

The cross-slot planter resulted in yields comparable to the Guelph planter. This was our first experience with this system and there were some aspects that could perhaps be improved. We are not confident that we were obtaining the desired fertilizer application rate. Also, increasing the weight on the planting units may be necessary to achieve proper penetration under some conditions. We believe that the cross-slot planter has potential advantages and should be investigated further.

In addition to comparison of planters and fertilizer placement, this study permitted an assessment of the adequacy of the phosphorus fertilizer recommendations for no-till corn based on the OMAF soil test. There were seven field experiments over three years in which fertilizer rates ranging from 1/2 to 4 x the recommended rate were applied as a side band with the Guelph planter. At none of the seven sites was there any response to fertilizer P application in excess of that recommended. Averaged over all seven sites, the recommended rate was the most profitable. At most sites, the soil test was low resulting in a recommended rate of 50 kg P_2O_5 ha^{-1} or greater. In 1990, when the recommended rates was lower, there was no response to fertilizer P. These data indicate that, even with low available P values, current recommendations are adequate.

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1.0 INTRODUCTION

This project was initiated in response to difficulties being encountered with conventional fertilizer placement systems on no-till corn planters. To overcome these difficulties, farmers have made various modifications, most of which have involved mounting of additional coulters in front of the seed unit to till the soil in a strip into which the seed and fertilizer could be placed. We thought that three recent developments required further testing and direct comparison. These developments were as follows:

a. Cross-slot planter.

Workers in New Zealand have developed a new planting system, called the cross-slot planter (or T-slot planter), which places the seed and fertilizer with almost no disturbance of the soil below the seed and minimum disturbance above the seed. The developers claim that this system creates an ideal environment for germination and early growth of the seed. The fertilizer can be placed at seed level or slightly below and to one side of the seed.

b. Strip-band fertilizer application.

Recent studies at Guelph (Barry and Miller 1989) have indicated that higher corn yields can be obtained if the phosphorus absorption during early growth can be increased above that usually achieved with the conventional placement 5 cm to the side and 5 cm below the seed. A John Deere 7000 planter was modified to apply fertilizer in two strips (6-8 cm wide) on either side of and slightly below the seed. This placement gave significantly higher corn yields than a 5 x 5 band at two sites in 1989 when fertilizer rate was above that currently recommended.

c. Coulter-strip fertilizer application.

A variation of the strip-band application has been developed and tested by Ray Rawson in Michigan. His system discharges the fertilizer at the front edge of a fluted coulter. The concept is that the fertilizer will be mixed in a small volume of soil into which the seed is placed. This system was reported to have resulted in a 10 to 15 bu ac^{-1} increase in yield in Michigan in 1989 compared to conventional fertilizer application.

2.0 OBJECTIVES

The objectives of this project were:

a. To compare the effectiveness of planting and fertilizer application using the cross-slot, strip-band and coulter-strip application systems.

b. To compare the cross-slot planter with a conventional system under varying soil conditions.

3.0 EXPERIMENTAL PROCEDURES

3.1 Development of planters.

3.1.1 Cross-slot planter

Four units of the cross-slot system were obtained from New Zealand and mounted on a New Idea planter by Jack Rigby. The purchase and mounting of the units was completed under a separate SWEEP-TED project. The original intention was to have this planter ready for testing during the 1990 growing season. However, due to delay in delivery of the units from New Zealand, this was not possible. The units were obtained and mounted during the fall and winter of 1990/91 and the planter was incorporated into three field experiments in 1991.

3.1.2. Shillinglaw planter

Four of the 8 planter rows on Bruce Shillinglaw's JD-7000 planter were modified so that fertilizer was deposited at the leading edge of a fluted coulter mounted in front of and about 5 cm to the side of the seed row. The idea was that the fertilizer would be incorporated in a strip by the coulter. This placement is referred to as the coulter strip. Fertilizer on the other 4 rows was placed as a band 5 cm to side and 5 cm below the seed which is referred to as the "side band".

3.1.3 Guelph planter

As part of an on-going research program for the Ontario Ministry of Agriculture and Food, a John Deere 7000 Conservation planter was converted in 1988 into an experimental planter capable of placing fertilizer in several positions relative to the seed. The dry fertilizer system was replaced with a liquid system because of the ease of handling using pumps and valves. The conventional fertilizer band opener was removed and replaced with a single

Table 1: Description of Planters Used in Study.

Planter	Model	Fertilizer Used	Placement Options
Cross-slot	Modified New Idea	10-34-0 Liquid	Side band (2-3 cm to side and 1-2 cm below seed)
Shillinglaw	JD-7000	13-52-0 dry	Side band (5 cm x 5cm) Coulter strip
Guelph	Modified JD-700	10-34-0 liquid	Side band (5 cm x 5 cm) Strip band With seed
Rigby	New Idea Series 900 Double frame	10-34-0 liquid	Side band (5 cm x 5 cm)

coulter with a liquid fertilizer tube. Two coulters (1/2" ripple) were installed on an additional tool bar in front of each seed unit. These coulters were about 10 cm on either side of the seed row. A fertilizer injection system was attached to each of these coulters. The system includes a shoe to lift the soil and a flat-fan spray jet under the shoe through which liquid fertilizer can be pumped under pressure. This system is designed to provide a strip band 6-8 cm wide 1-2 cm below and on either side of the seed. The principle involved is that these bands will intercept most of the seminal roots of corn shortly after emergence and hence result in earlier and greater absorption of P. This placement is referred to as the "strip band".

In addition to a conventional side band (5 cm to side and 5 cm below seed) and the strip band, fertilizer can be placed directly with the seed.

3.2 Field Sites

Experiments were conducted at two sites in 1990 and three sites in 1991. Information on the sites and their general management is provided in Tables 2 and 3.

3.3 Treatments

The treatments varied somewhat from site to site depending on planter availability, P fertilizer requirement and planting conditions. Listings of the specific treatments at each site are provided in the tables of results. A summary description follows.

3.3.1 Huron Co. - 1990

The strip band and side band were compared at four rates of 10-34-0 ranging from 1/2 to 4 x recommended. Treatments were also included in which fertilizer (10-34-0) was applied only with the seed at a rate of 5 kg P ha^{-1} and in which no fertilizer was applied.

The coulter-strip fertilizer placement was compared with the side band using the Shillinglaw planter at the recommended and 2 x recommended P rates. A check (no fertilizer) was included. Because the Shillinglaw planter was equipped only for dry fertilizer, monoammonium phosphate (13-52-0) was used. There is ample evidence that liquid and dry fertilizer with the same formulation

applied in the same position are equally effective (Baweja and Bates 19 Although some ammonium polyphosphate is used in 10-34-0, polyphosphates have be. shown to be as effective as ortho-phosphates in increasing P absorption (Dick and Tabatabai, 1987).

There were four replicates of each treatment in a split plot design with planter the main plot and fertilizer rate and placement as the split plot.

3.3.2 Oxford Co. - 1990

Only the Guelph planter was used at this site. The strip band was compared with the side band at fertilizer rates (10-34-0) ranging from 1/2 to 3x recommended P. Because of the lower P soil test (higher fertilizer P requirement) it was not possible to apply 4 x the recommended rate. A check treatment and a treatment of fertilizer with the seed only were included.

There were six replicates of each treatment in a split plot design with fertilizer rate the main plot and placement the split plot.

3.3.3 Kent Co. - 1991

Three planters were used at this site, the Guelph and cross slot planters as well as the regular farm planter used by Jack Rigby. The strip band and side band were compared using the Guelph planter at four fertilizer rates (10-34-0) ranging from 1/2 to 2x recommended P. A check treatment (no fertilizer) and a treatment of the recommended P rate as a side band plus fertilizer with the seed were also included. The latter treatment was used to see if the combination would provide greater early P absorption than the side band alone.

Treatments with the cross-slot planter included a check (no fertilizer), the recommended, and 2x the recommended P rates.

A check and recommended P rates were used with the Rigby planter. However, it was apparent from early growth and P absorption data that the fertilizer application system was not functioning during planting, so only the check treatment is reported.

Two replicates of the Guelph and cross-slot planters were planted on May 3 but it was decided that the soil was too wet to continue. Rain occurred before the soil dried sufficiently so the remaining three replicates with Guelph and

Table 2: Soil and Management Information - 1990 sites

	Site 1	Site 2
Location	Belltane Farms B. Shillinglaw Huron Co.	Hartholm Farms Bob Hart Oxford Co.
Soil Texture	Silt loam	Loam
Soil Test - P K pH	18 100 7.6	9 75 6.9
Previous Crop	Red Clover	Corn
Tillage	None	Fall chisel plow, spring cultivate
Planters	(G) Guelph (S) Shillinglaw	Guelph
Fertilizer N K	 80 kg N ha^{-1} as anhydrous None	 180 kg N ha^{-1} as 28% 150 kg K_2O ha^{-1} broadcast
Herbicide	Red Clover burnoff - Roundup and 2-4D Fall - Repeated in spring - Marksman (Dicamba/atrazine) at 3-leaf	Dual - pre-emerge Banvel - post-emerge
Planting Date	- May 24	- May 15
Hybrid	- GL 220	Pion. 3790

Table 3: Soil Management Information - 1991 Sites

	Site 1	Site 2	Site 3
Location	Rigby farm Jack Rigby Kent Co.	Beltane Farms B. Shillinglaw Huron Co.	Hartholm Farms Bob Hart Oxford Co.
Soil Texture	Sandy loam	Loam	Loam
Soil Test -P K pH	10 100 6.7	6 115 7.6	6 97 7.1
Previous Crop	Soybeans	Timothy	Soybeans
Tillage	None	Light discing	None
Planters	G- Guelph CS- Cross slot R - Rigby	G- Guelph CS- Cross slot S - Shillinglaw	G- Guelph CS- Cross slot
Fertilizer N K	 150 kg ha^{-1} as 28% side dressed 100 kg K_2O ha^{-1} broadcast	 160 kg ha^{-1} as urea broadcast prior to discing 100 kg K_2O ha^{-1} broadcast	 160 kg N ha^{-1} as 28% side dressed 150 kg K_2O ha^{-1} broadcast
Herbicide Burndown Weed Control	 1.25 L Ha^{-1} 2-4D 1.8 L ha^{-1} Roundup + $(NH_4)_2SO_4$ and Agral 90 2 L ha^{-1} Dual pre-emerge 3.7 L ha^{-1} Marskman post-emerge	 3.5 L ha^{-1} roundup plus 1.25 L ha^{-1} 2-4D followed by gramoxone 2.25 L ha^{-1} Dual plus 3L ha^{-1} Banvel	 None 2.5 L ha^{-1} Dual pre-emerge
Planting Date	Reps 4 and 5 - May 3 Reps 1, 2 and 3 - May 15	May 22	May 8
Hybrid	DK 485	GL 226	Pioneer 3790

cross-slot planters and four replicates with the Rigby planter were planted on May 15.

A split plot design was used with planters as the main plot and rate and placement as the split plot.

3.3.4 Huron Co. - 1991

Three planters, Guelph, cross-slot and Shillinglaw were used at this site.

Planting conditions at this site were very unfavourable. The dense timothy sod, although adequately killed, prevented the soil from drying following early May rains. The site was disced lightly on May 18 to break the mulching effect. Although the soil dried sufficiently to allow planting on May 22, the dense root below the discing depth made penetration difficult. The strip band units on the Guelph planter would not function adequately under these conditions so were removed. Treatments with the Guelph planter included a check plus the side band at four fertilizer rates (10-34-0), each with and without an additional amount of fertilizer with the seed.

Treatments with the cross slot planter included a check, 1/2 and recommended rates of P (as 10-34-0). Penetration and slot closing by the cross-slot planter was not as good as desired due to the dense timothy root mat. This problem was not as severe at the other two sites, but it does suggest that increased weight on the planter units may be advisable.

The coulter strip and side band application systems were compared with the Shillinglaw planter at 1/2 and recommended P rates using 13-52-0. A check was also included. There was very little soil disturbance with the coulter so little mixing of fertilizer with soil in the coulter strip application.

There were five replicates arranged in a split plot design with planters as the main plot and fertilizer rate and placement as the split plot.

3.3.5 Oxford Co. - 1991

The strip band and side band were compared using the Guelph planter at four rates of fertilizer (10-34-0) ranging from 1/2 to 2 x recommended P. A check treatment (no. fertilizer) and a treatment of the recommended P rate as a side band plus fertilizer with the seed were also included.

Fertilizer rates (10-34-0) used with the cross slot planter included a check, (no fertilizer) 1/2 and recommended P rates.

There were four replicates with planters as the main plot and fertilizer rate and placement as the split plot.

3.4 Sampling and Analytical Procedures

3.4.1 Emergence

Emergence counts were taken on selected treatments in 1991 at the Kent Co. and Huron Co. sites. The number of plants emerged in 10 m of row was determined periodically following planting. Data are presented as % of final plant counts.

3.4.2 Early shoot growth and nutrient concentrations

Ten shoot samples were collected from each plot at varying growth stages (see results section for details), dried at 70°C, weighed and ground. Samples were analyzed for N, P and K by the Analytical Services Laboratory of the Dept. of Land Resource Science using the method of Thomas et al. 1967.

3.4.3 Leaf nutrient concentration at silking

Leaf samples were collected from 10 plants in each plot when approximately 50% of plants were silked. The mid-third of the leaf opposite and below the ear was dried and ground. Samples were analyzed by the Analytical Services Laboratory, Dept. of Land Resource Science for N, P, K, Ca, and Mg using the method of Thomas et al. (1967), for Zn, Mn, and Cu, using a dry ashing procedure (Isaac and Kerber 1971) and for B by the method of Basson et al. 1969.

3.4.4 Time of silking

The number of plants silked in 10 m of row in each plot was determined at a time when differences due to treatment were expected to be the greatest. The data are presented as % of plants silked on a specific date.

3.4.5 Final yield measurements

Cobs were removed by hand from 10 m of row (5 m from each of two centre rows in a four-row plot) and weighed. A sub-sample of 10 representative cobs was weighed, dried at 70°C, shelled and the dry grain weight determined. The data were used to calculate ear moisture at harvest, and final grain yield.

3.4.6 Soil sampling

A composite soil sample was collected from the whole plot area at each site prior to planting to determine the need for a potash application and to establish the recommended rate of P.

After planting in 1991, samples were collected from blocks within replicates to determine the uniformity of soil test within and between replicates.

3.4.7 Establishment of fertilizer band position

The position and distribution of the fertilizer band in relation to the seed was determined for the different fertilizer placements at the Huron Co. site in 1990 and at the Kent Co. and Huron Co. sites in 1991.

A shallow pit was dug in the row to expose a face 20 cm wide and 10 cm deep perpendicular to the row. A piece of plywood with holes drilled at 2-cm intervals both vertically and horizontally was placed against this face and the position of the seed noted. Small soil samples were taken by inserting a 1.25-cm diameter cork borer through each hole and into the soil as far as possible. Samples were collected from plots receiving the highest fertilizer rate from the area of the face thought necessary to include the fertilizer band and analyzed for available P ($NaHCO_3$ extractable) by the Analytical Services Laboratory of the Department of Land Resource Science.

Measurements were used to develop a plot of zones of soil having varying levels of available P.

3.4.8 Statistical Analysis

Analyses of variance were performed on all data sets. Standard errors are presented for the individual treatment means in each table. Comparison of treatment effects were made by calculating the appropriate LSD for differences between individual treatments or combinations of treatments. All differences discussed in the text are significant at $P \leq 0.05$ unless otherwise indicated.

3.4.9 Measurement of soil temperature and moisture

The original proposal for the 1991 studies included measurement of soil temperature and moisture in the seed row at the Kent Co. site. These parameters,

which have an important influence on germination, may differ amongst planters due to the degree of soil disturbance. We were not, however, able to complete these measurements. Temperature sensors were installed, but the recording system malfunctioned. Time pressures because of the weather prevented the collection of soil moisture samples until it was too late to obtain meaningful data.

4.0 RESULTS AND DISCUSSION

Means for each treatment of all parameters measured at each site are presented in Tables A1 to A13 in the appendix. Summary tables of the most relevant data are presented and discussed in this section in relation to the following comparisons of interest: (1) comparison of fertilizer placement methods; (2) comparison of the cross slot planter with the Guelph planter and farmer planters; (3) assessment of adequacy of fertilizer P recommendations based on the OMAF test.

4.1 Comparison of fertilizer placement methods

The strip band and side band were compared using the Guelph planter at two sites in each of 1990 and 1991. They were also compared at two sites in 1989 in an earlier project funded under the OMAF/University contract and the fertilizer industry. Some data from the 1989 experiments are included here to provide a more complete evaluation of the comparison.

In addition to the comparison of the strip band and side band, treatments were included with the Guelph planter where fertilizer was applied with the seed either alone or in combination with a side band.

A third comparison of fertilizer placement methods was with the Shillinglaw planter where a coulter strip application was compared to a side band.

Each of these three comparisons is discussed in the following sections.

4.1.1 Comparison of side band and strip band using the Guelph planter

4.1.1.1 Early shoot growth and nutrient content

Shoot samples were taken at three growth stages at both sites in 1990, and at the Kent Co. and Huron Co. sites in 1991. Because of very rapid early growth at the Oxford Co. site in 1991, only two shoot samples were taken. The shoot dry weight and N, P and K concentrations for all treatments at each sampling are

presented in appendix tables. Data for the side band and strip band treatments at the 5 to 7 leaf stage are presented in Tables 4 and 5. This is the stage at which a growth response to P would be expected to be most apparent.

Shoot dry weight increased with increasing fertilizer application at all sites except the Huron Co. - 1990 site. There were no significant differences in shoot dry weight between the side band and strip band at any site. The shoot phosphorus concentration also increased with increasing fertilizer rate at all sites. Shoot P concentration was greater with the side band than the strip band at the two highest rates at the 1990 Oxford site but there were no significant differences at any rate at the other three sites.

These data indicate that the strip band was not superior to the side band in terms of early shoot growth and P absorption.

4.1.1.2 Time of silking and final grain yield

The percentage of plants silked on specific dates for each site is presented in appendix tables. There was a marked increase in percentage silking between the check and 1/2 recommended fertilizer rate at all sites but increasing fertilizer rate caused a further increase in silking only at the Oxford 1990 site. There was no significant effect of fertilizer placement on percentage silking at any of the four sites.

A comparison of yields with the strip band and side band in 1991 is shown in Table 6. Because there was no response to P application at either site in 1990 (see Tables A2 and A4), comparison of methods of application was not possible. Hence the 1990 results are not included in Table 6.

Although yields with the strip band appeared to be slightly greater than the side band, the differences were not significant at either site. The interaction between placement and fertilizer rate was also not significant.

Drought conditions at the Kent Co. site resulted in somewhat lower yields than might be expected for that region. In addition, yields were highly variable (CV = 16.5%) resulting in a high standard error of means. Yields were higher than normal at the Oxford Co. site and variability was normal (CV=7.0%).

The mean yields from two sites in each of 1989 and 1991 are presented in

Table 7. The trend of slightly greater yields with the strip band occurred in 1989 as well as 1991. A statistical analysis involving all four sites indicated that the strip band was superior to the side band at a probability, level of 0.078. Given the consistency of the trend and the statistical probability it can be concluded with reasonable confidence that the strip band is slightly superior to the side band. The difference, however, is small and about the same as has frequently been observed from an application of a low rate of liquid fertilizer directly with the seed. Application of fertilizer with the seed can be achieved with minor modification to the planter compared to that required to achieve the strip band. Therefore, it is not appropriate to recommend that farmers use the strip band application system.

4.1.2 Fertilizer application with the seed using the Guelph planter

The practice of applying a small amount (10-15 kg P_2O_5 ha^{-1}) of liquid fertilizer with the seed has been shown to result in small increases (150 to 200 kg ha^{-1}) in grain yield over that obtained with either broadcast or banded P, or when no fertilizer P was recommended (Bates 1971, 1985, 1986, Hart 1989).

Two questions were addressed in this project. (1) Will a small amount of fertilizer placed with the seed replace the requirement for larger amounts banded? (2) Will an application with the seed in addition to the recommended amount banded result in increased yield?

A treatment was included at both sites in 1990 and at the Huron Co. site in 1991 in which fertilizer was applied only with the seed. The early shoot growth and P concentration as well as the final grain yield are presented in Table 8 for the check, with-seed only and recommended P (as a side band) treatments.

Fertilizer with the seed resulted in a greater shoot P concentration than either the check or the greater amount of fertilizer as a side band at the first sampling at all sites. At the second and third samplings, a difference was apparent only at the Huron 1991 site. There were no differences in shoot growth

Table 4: Comparison of early shoot dry weight (DM) and nutrient concentration with side band and strip band - 1990.

Placement	P Rate	Oxford Co[1]				Huron Co[2]			
		DM	Nut. Conc.			DM	Nut Conc.		
			N	P	K		N	P	K
		g pl^{-1}	g kg^{-1}			g pl^{-1}	mg g^{-1}		
Side band	1/2	0.71	41.9	3.5	46.5	1.28	3.98	4.3	27.9
	Rec	0.94	43.3	4.0	44.5	1.23	40.8	4.3	33.4
	2 x	1.11	45.8	4.5	44.4	1.23	45.9	4.9	36.6
	3 x	1.15	45.5	4.8	43.5	-	-	-	-
	4 x	-	-	-	-	1.38	42.8	5.0	32.6
Strip band	1/2	0.82	41.8	3.7	43.6	1.29	41.0	4.3	33.4
	Rec	0.82	42.2	3.9	41.6	1.25	40.8	4.2	34.4
	2 x	0.88	44.1	4.0	41.8	1.15	41.3	4.2	36.9
	3 x	1.01	42.8	4.1	44.6	-	-	-	-
	4 x	-	-	-	-	1.31	43.2	4.8	30.2
Standard error of means[3]		0.16	0.80	0.12	2.18	0.30	1.82	0.21	3.15
Recommended P (kg P_2O_5 ha^{-1})		45				20			

[1]) 5 to 7 leaf stage
[2]) 7 to 8 leaf stage
[3]) For Oxford Co., n=6, Huron Co., n=4

Table 5: Comparison of early shoot dry weight (DM) and nutrient concentration with side band and strip band - 1991.

Placement	P Rate	Kent Co				Oxford Co			
		D.M.	Nut. Conc			D.M.	Nut. Conc		
			N	P	K		N	P	K
		(g pl^{-1})	g kg^{-1}			g pl^{-1}	g kg^{-1}		
Side band	1/2 x	0.98	41.1	5.7	44.5	0.93	44.1	5.4	52.2
	Rec	1.24	44.3	7.4	46.8	0.91	44.8	5.3	48.5
	1 1/2 x	1.37	45.0	7.5	44.5	0.89	46.0	6.3	50.5
	2 x	1.25	44.3	7.7	42.4	0.99	46.6	6.5	48.9
Strip band	1/2 x	0.98	39.9	5.5	47.9	0.92	42.4	4.4	54.2
	Rec	0.93	40.8	6.5	50.2	1.04	44.7	5.4	49.6
	1 1/2 x	1.14	42.3	6.7	41.7	1.04	44.6	5.2	45.6
	2 x	1.17	42.2	7.6	45.6	1.20	44.1	6.0	44.6
Standard error of means[1]		0.09	1.23	0.45	2.31	.08	1.07	0.31	2.53
Recommended P (kg P_2O_5 ha^{-1})		50				90			

[1]For Kent Co, n=5, Oxford Co, n=4

Table 6 Corn grain yields with a strip band and side band fertilizer application-1991 sites.

Site	P_2O_5 Rec	Place	P applied				
			1/2 x	Rec	1 1/2 x	2 x	Mean
	(kg ha^{-1})		(t ha^{-1} @ 15.5% moist)				
Kent Co.	50	side	8.91	9.67	8.62	8.77	8.99
		strip	9.41	9.79	9.80	9.14	9.54
Standard error of means = 0.75 (n=5)							
Oxford Co.	90	side	10.62	11.61	10.51	10.81	10.89
		strip	11.30	11.50	10.92	10.94	11.17
Standard error of means = 0.37 (n=4)							

Table 7: Corn grain yield with a strip band and side band fertilizer application - means for 1989 and 1991 sites.

		P applied			
Year	Place	1/2 x	Rec.	1 1/2 x	Mean
		(t ha^{-1} @ 15.5% moisture)			
1989	Side	7.80	8.42	8.42	8.21
	Strip	8.05	8.49	8.99	8.51
1991	Side	9.76	10.64	9.56	9.99
	Strip	10.36	10.65	10.36	10.46
Mean	Side	8.78	9.53	8.94	9.10
	Strip	9.20	9.57	9.96	9.48

at the first sampling at any site in 1990. At the second and third samplings at both sites in 1990 and at all three samplings at the Huron Co. 1991 site, fertilizer with the seed and the side band increased shoot dry matter to a similar extent compared to the check. The difference in response at the first sampling is likely due to the stage of sampling. Increase in shoot dry matter has frequently been observed to occur a few days after an increase in shoot P concentration. As indicated by shoot dry matter, the plants were at a slightly more advanced stage at the Huron - 1991 site.

There was no yield increase with fertilizer at any rate in 1990. There was a large increase with the recommended rate at the Huron Co.-1991 site, but fertilizer with the seed did not increase yield compared to the check. These results confirm observations from previous studies that the application of fertilizer with the seed will not replace a band application where the fertilizer P requirement is above the minimum recommended (20 kg P_2O_5 ha^{-1}).

The early shoot growth and final yield when fertilizer is applied with the seed in addition to a side band are presented in Table 9. Application with the seed increased the shoot P concentration compared to the side band at the first sampling at all three sites but there were no significant differences at later samplings. The increased early P absorption did not result in increased shoot dry matter at any sampling or in final grain yield. It is important to recognize that there was no increase in yield with fertilizer rates greater than recommended at these sites so a yield response to the increased P application in the with-seed treatment would be expected to occur only if the increased early P concentration was important for final yield. It is apparent that at these sites, that was not the case. This may appear contradictory to the results of the studies by Barry and Miller (1989) discussed in Section 1.0. Those studies were conducted in an outdoor hydroponic system in which there were no limiting factors at later stages of growth. It is possible that limiting factors in the field trials of this project prevented the increased yield potential due to early P absorption from being realized.

Table 8: Response of early shoot dry matter (DM) and P concentration and grain yield to fertilizer with the seed compared to the recommended rate as a side band.

Treatment	Shoot D.M.[1]			Shoot P conc[1]			Grain Yield
	1	2	3	1	2	3	
	g plant^{-1}			g kg^{-1}			t ha^{-1} @ 15.5%
Oxford Co. - 1990							
Check	0.19	0.67	1.40	3.7	3.5	3.5	8.29
With seed	0.24	0.88	2.02	4.5	3.5	3.5	8.20
Side band[2]	0.22	0.94	1.72	3.9	4.0	3.8	8.39
Standard error of means (n=6)	0.01	0.05	0.12	0.18	0.12	0.12	0.22
Huron Co.-1990							
Check	0.08	0.29	1.04	3.6	3.9	4.3	6.28
With seed	0.09	0.39	1.40	4.6	4.3	4.3	5.80
Side band[2]	0.10	0.33	1.23	3.6	4.2	4.1	6.22
Standard error of means (n=4)	0.005	0.03	0.10	0.16	0.21	0.21	0.22
Huron Co.-1991							
Check	0.20	0.45	2.68	3.0	3.3	2.7	5.62
With seed	0.28	0.72	3.90	5.2	6.0	4.2	5.45
Side band	0.29	0.73	5.90	4.8	4.7	3.0	7.91
Standard error of means (n=5)	0.02	0.07	0.56	0.25	0.21	0.13	0.50

[1]1, 2, 3 refer to samplings. See appendix tables for leaf stages.
[2]Side band fertilizer rates (kg P_2O_5 ha^{-1}): Oxford 1990-50: Huron 1990-20; Huron 1991-90.

Table 9: Response of early shoot dry matter (DM) and P concentration and grain yield to an application of fertilizer with the seed in addition to a side band at the recommended rate.

Treatment	Shoot D.M.[1]			Shoot P Conc[1]			Grain Yield
	1	2	3	1	2	3	t ha^{-1} @ 15.5%
Kent Co.-1991	g plant^{-1}			g kg^{-1}			
Check	0.68	1.92	3.94	3.6	3.3	3.4	8.60
Side band[2]	1.24	3.59	7.00	7.4	6.0	4.3	9.67
Side band/with seed	1.09	3.79	7.77	8.5	6.7	4.7	8.54
Standard error of means (n=5)	0.09	0.25	0.56	0.45	0.38	0.22	0.75
Huron Co.-1991							
Check	0.20	0.45	2.68	3.0	3.3	2.7	5.62
Side band[2]	0.29	0.72	5.90	4.8	6.0	4.2	7.91
Side band/with seed	0.31	0.75	5.22	5.7	6.2	4.4	7.61
Standard error of means (n=5)	0.02	0.07	0.56	0.25	0.21	0.13	0.50
Oxford Co.-1991							
Check	0.57	2.89	-	3.3	3.1	-	9.20
Side band[2]	0.91	5.67	-	5.3	4.1	-	11.61
Side band/with seed	0.94	5.30	-	5.7	3.7	-	10.34
Standard error of means (n=4)	0.08	0.50	-	0.31	0.13	-	0.37

[1])1, 2, 3, refer to samplings. See appendix tables for leaf stages. Only two samples taken at Oxford site.
[2]Side band fertilizer rates (kg P_2O_5 ha^{-1}): Kent-50; Huron-90; Oxford-90.

4.1.3 Comparison of coulter strip and side band using the Shillinglaw planter

As indicated in section 3.1.2, four rows on a JD-7000 planter were modified so that fertilizer was deposited at the leading edge of a fluted coulter mounted in front of and about 5 cm to the side of the seed row. This "coulter strip" application was compared to the conventional side band on the other four rows of the same planter. All rows had the same arrangement of coulters and planting units; only the point of fertilizer dispensing changed. These two methods of fertilizer application were compared at the Huron Co. sites in 1990 and 1991. Early shoot growth and P concentration and final grain yield are presented in Table 10.

Both the side band and coulter strip application increased the early shoot growth and P concentration compared to the check in both years, particularly at the recommended fertilizer rate. There were, however, no significant differences between the two methods. Final grain yield was not increased by fertilizer application in 1990. There was a significant increase in grain yield in 1991 but there was no significant difference between the two placement methods.

These two experiments do not give a good evaluation of the coulter strip method because of the lack of response to P in 1990 and the very poor seedbed in 1991. The degree of mixing of the fertilizer by the coulter in 1991 was much less than it would be in a more normal seedbed.

4.1.4 Uniformity of soil tests at 1991 site.

Because of the large area used for the experimental plots and because the design resulted in the replicates running the full length of the plot area, soil samples were collected from three blocks within each replicate at each of the three sites to determine the uniformity of the soil and to provide information that might be useful in interpretation of variation within and between replicates. The data are presented in Table 11. The available P and K concentrations were surprisingly uniform at all three sites. Although there was

Table 10: Response of early shoot dry matter (DM) and P concentration and grain yield to a coulter strip and side band fertilizer application in Huron Co.

Fert. Place	Fert. P Appl.	Shoot D.M.			Shoot P Conc.			Grain Yield
		1	2	3	1	2	3	t ha^{-1} @ 15.5%
	kg P_2O_5 ha^{-1}	g $plant^{-1}$			g kg^{-1}			
1990								
Check	0	0.08	0.34	1.18	4.3	4.1	4.3	6.49
Side band	22	0.09	0.35	1.48	4.4	4.0	4.5	6.97
	44	0.10	0.44	1.53	5.2	4.8	4.8	7.38
Coulter strip	22	0.08	0.32	1.39	4.4	4.5	4.5	7.21
	44	0.08	0.38	1.70	4.8	4.7	4.5	6.61
Standard error of means (n=4)		0.005	0.03	0.10	0.16	0.21	0.21	0.22
1991								
Check	0	0.19	0.53	3.67	2.9	3.8	2.9	7.16
Side band	45	0.20	0.56	5.56	3.1	4.0	3.1	8.13
	90	0.24	0.62	5.18	3.9	4.3	3.1	8.04
Coulter strip	45	0.22	0.61	4.96	3.3	4.3	3.1	8.18
	90	0.22	0.69	6.58	3.5	4.7	3.3	9.12
Standard error of means (n=5)		0.02	0.07	0.56	0.25	0.21	0.13	0.50

Table 11: Uniformity of available P, K and pH at 1991 sites.

Rep	Block*	Site 1 Kent Co.			Site 2 Huron Co.			Site 3 Oxford Co.		
		P	K	pH	P	K	pH	P	K	pH
1	1	9	91	6.4	7	92	7.3	7	156	7.0
	2	11	102	6.5	7	90	7.4	6	90	7.1
	3	11	90	6.4	10	94	7.5	7	94	7.0
2	1	10	88	6.7	7	99	7.6	7	115	6.8
	2	14	100	7.1	8	107	7.6	6	85	6.8
	3	11	113	6.9	6	103	7.6	6	96	6.5
3	1	12	93	6.5	10	107	7.6	8	119	6.5
	2	13	101	7.1	7	106	7.6	6	94	6.5
	3	15	91	7.0	6	101	7.6	5	128	6.6
4	1	9	85	6.7	7	99	7.6	7	152	6.6
	2	10	111	6.4	6	106	7.6	5	155	6.6
	3	13	135	6.8	10	111	7.6	5	115	6.7
5	1	-	-	-	6	103	7.5	-	-	-
	2	-	-	-	6	111	7.6	-	-	-
	3	-	-	-	7	105	7.5	-	-	-

*Each replicate was divided into three blocks along the length of the plot area. Blocks 1 and 3 are from opposite ends of the plot area and block 2 from the middle.

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a greater variation in pH, particularly at the Kent Co. site, this variation was not sufficient to affect the results.

4.1.5 Position of fertilizer bands

As indicated in section 3.4.6, soil samples were taken at the Kent Co. and Huron Co. sites in an attempt to determine precisely the position of the fertilizer bands. This exercise was not entirely successful. Although the area sampled should have included the fertilizer bands in all cases, no fertilizer concentration was observed in several instances. This may be because the fertilizer injection is not as continuous as we thought. The samples were taken by inserting a core sampler about 2 cm into the face of a pit dug perpendicular to the row. Thus if there was a gap in fertilizer delivery over that distance, no concentration would be detected. In addition, it was not always possible to locate the position of the seed precisely. Thus the horizontal and vertical distance of the band in relation to the seed could not be determined as accurately as desired.

In spite of these difficulties, it was possible to locate the band position with most of the placement methods on at least one plot. The results are presented in Figures 1 to 4 in the appendix. The side band (Fig. 1) and strip band (Fig. 2) placements with the Guelph planter were in the expected positions. Also as expected, the maximum concentration of P was greater in the side band. All the fertilizer is injected at one point with this placement whereas with the strip band, the fertilizer is in contact with a greater volume of soil. The cross slot planter (Fig. 3) appeared as expected to be placing the fertilizer considerably closer to the seed than the Guelph side band. The most concentrated region, however, was further from the seed (about 5 cm) than anticipated. Sampling of this placement was done to a distance of only 4 cm to the side of the row resulting in only a partial sampling of the band as indicated in Figure 3. The coulter strip application with the Shillinglaw planter did not appear to mix the fertilizer into the soil to a significant depth (Fig. 4). The data presented in Figure 4 are from a 1990 sampling. Similar results were obtained in 1991 but are not presented because it was obvious during planting that there was little

mixing by the coulter because of the dense timothy sod. This problem was not as apparent in 1990.

4.2 Comparison of cross slot planter with other planters.

The cross slot planting system assembled by Jack Rigby was included at three sites in 1991 in comparison with the Guelph experimental planter and, at two of the three sites, with the no-till planters used by the cooperating farmers. Comparisons involving the cross slot and Guelph planters included a check in which no fertilizer was applied, and two rates of 10-34-0 liquid fertilizer based on the requirements by soil test. Comparison with the Rigby planter was with no fertilizer only while that with the Shillinglaw planter included a check and two rates using 10-34-0 in the cross slot and 13-52-0 in the Shillinglaw planters.

4.2.1 Emergence, early shoot dry matter and P concentrations

Emergence counts were taken on selected treatments at the Kent Co. and Huron Co. sites. Emergence was most rapid with the Guelph planter at both sites, intermediate with the cross slot planter and slowest for the farmer planters (Table A7 and A10). There was no apparent effect of fertilizer application on emergence. The more rapid emergence with the Guelph planter may have been due to either depth of planting or an improved seed bed resulting from the greater degree of soil disturbance. Because the actual seed drop was not known, it was not possible to determine the % emergence.

Shoot dry matter and P concentration at the 4 to 6 leaf stage are presented in Table 12. The data are for the side band fertilizer application with the Guelph and Shillinglaw planters.

There were no significant differences in shoot dry matter between the cross slot and Guelph planters at any of the sites when no fertilizer was added nor at the Kent Co. and Huron Co. sites at either rate of fertilizer. At the Oxford Co. site early shoot growth with fertilizer added was significantly greater with the Guelph planter.

Shoot P concentrations with the cross slot and Guelph planters were not significantly different when no fertilizer was applied at any site. When

fertilizer was applied, there was a trend for the shoot P concentration to be greater with the Guelph planter at all three sites. This difference was significant at the recommended fertilizer rate at the Huron Co. site and at the 1/2 recommended rate at the Oxford Co. site. These differences may have been caused by a less-than-intended fertilizer application with the cross slot planter rather than by a less favourable placement. Although the cross slot planter was delivering the desired rate when the units were not in the ground, we suspect there may have been partial blocking of the delivery tubes when the units were in the ground. There was no flow rate indicator on the planter.

There was no difference in either shoot dry matter or P concentration between the cross slot and Rigby planters.

Shoot dry matter and P concentration were similar for the cross slot and Shillinglaw planters when no fertilizer was applied, but both shoot dry matter and P concentration were significantly greater with the cross slot planter when fertilizer was applied. This could be due to the difference in placement although a difference in rate of application can not be ruled out. There was no way to monitor the delivery rate of dry fertilizer with the Shillinglaw planter. The calibration provided in the manual was assumed to be correct. The difference in fertilizer material (10-34-0 and 13-52-0) is not thought to be a likely cause of the difference.

4.2.2 Grain yields

Grain yields for the different comparisons are presented in Table 13. There were no significant differences in grain yield between the cross slot and Guelph planters at any fertilizer rate at any of the three sites. The only significant difference in grain yield was between the Guelph and Shillinglaw planters when no fertilizer was applied.

A similar observation was made in 1990 when the grain yields with the Shillinglaw planter were higher than those with the Guelph planter at all fertilizer rates (Table A2). This was associated with a greater P concentration during early growth, even when no fertilizer was applied. This difference in early shoot P when no fertilizer was applied was also found in 1991 although the

Table 12: Early shoot dry matter and P concentration with different planters in 1991.

	Fertilizer P rate							
Site/Planter	0		1/2 Rec		Rec		2x Rec	
	DM	P	DM	P	DM	P	DM	P
	g pl^{-1}	g kg^{-1}	g pl^{-1}	g kg^{-1}	g pl^{-1}	g kg^{-1}	g pl^{-1}	g kg^{-1}
Kent Co.[1]-1991								
Cross slot[2]	0.43	4.2	-	-	0.59	7.1	0.72	7.6
Guelph[2]	0.44	3.4	-	-	0.71	8.2	0.76	8.3
Rigby	0.42	3.9	-	-	-	-	-	-
Standard error of means: DM = 0.09; P = 0.45 (n=5)								
Huron Co.-1991								
Cross slot	0.48	3.6	0.71	4.9	0.83	5.1	-	-
Guelph	0.45	3.3	0.74	5.0	0.72	6.0	-	-
Shillinglaw	0.53	3.8	0.56	4.0	0.62	4.3	-	-
Standard error of means: DM = 0.07; P = 0.21 (n-5)								
Oxford Co-1991								
Cross slot	0.46	3.1	0.65	4.2	0.71	4.9	-	-
Guelph	0.57	3.3	0.93	5.4	0.91	5.1	-	-
Standard error of means: DM = 0.08; P = 0.31 (n=4)								

[1]Leaf stages: Kent Co., 4-6; Huron Co., 4-5; Oxford Co., 4-6.
[2]DM and P conc taken from reps 1 to 3 only, which were planted at same time as all 4 reps with Rigby planter.

Table 13: Grain yields with different planters in 1991.

	Fertilizer P rate			
Site/Planter	0	1/2 Rec	Rec	2x Rec
	tonnes ha^{-1} @ 15.5% moisture			
Kent Co.				
Cross slot	8.18	-	9.48	8.77
Guelph	8.60	-	9.67	8.85
Rigby	9.05	-		
Standard error of means = 0.75 (n=5)				
Huron Co.				
Cross slot	6.18	7.63	8.01	-
Guelph	5.62	7.12	7.91	-
Shillinglaw	7.16	8.13	8.04	-
Standard error of means = 0.50 (n=5)				
Oxford Co.				
Cross slot	9.58	10.33	10.61	-
Guelph	9.20	10.62	11.61	-
Standard error of means = 0.37 (n=4)				

difference was not quite significant at a 5% probability level.

These differences between the Guelph and Shillinglaw planter may be due to the effect of differences in soil disturbance on the vesicular arbuscular mycorrhizal symbiosis. Tillage has been found to decrease the effectiveness of the mycorrhizal symbiosis and hence decrease the absorption of P during early growth (McGonigle et al. 1990). The Guelph planter causes more soil disturbance in the planting row than the Shillinglaw planter.

4.2.3 Summary

The results with the cross slot planter are quite promising given that it was our first experience with it. With modifications to overcome some of the problems encountered, it has potential to be a superior planting system. The greatly reduced disturbance should maximize the effectiveness of the mycorrhizal symbiosis, which would reduce the amount of fertilizer phosphorus required at planting.

4.3 Assessment of adequacy of fertilizer P recommendations

Over the duration of this study (1989 to 1991), fertilizer phosphorus rates ranging from 0 to 2x that recommended according to the soil test have been applied at seven sites using the Guelph planter. With only one exception (Huron Co.-1990) all sites had a fertilizer P requirement of 50 kg P_2O_5 ha^{-1} or higher. These sites therefore provide a useful evaluation of the adequacy of current recommendations based on the OMAF soil test. Data are presented for the side band application for three years at the Oxford Co. site in Table 14 and as a mean of all sites in each year in Table 15.

At none of the seven sites was there a response to fertilizer P application in excess of that recommended. Averaged over all seven sites, the recommended rate was the most profitable. In 1990 when the recommended rates were lower, there was no response to fertilizer P.

These data indicate that even with low available P values, current recommendations are adequate. At medium soil test values current recommendations may be greater than can be justified on an economic basis.

It must be recognized that, because 10-34-0 was used as the fertilizer,

Table 14: Response of grain yield to fertilizer P in Oxford Co. - 1989 - 1991.

Year	Rec P	P Applied			
		0	1/2 Rec	Rec	2x Rec
	(kg P_2O_5 ha^{-1})	t ha^{-1} @ 15.5% moisture			
1989	50	7.99	8.76	9.05	9.09
1990	50	8.29	7.95	8.39	8.29
1991	90	9.20	10.62	11.61	10.81
Mean		8.49	9.11	9.68	9.40

Table 15: Mean response of grain yield to fertilizer P 1989-1991.

Year	Mean Rec P	P Applied			
		0	1/2 Rec	Rec	2x Rec
	kg P_2O_5 ha^{-1}	t ha^{-1} @ 15.5% moisture			
1989 (2 sites)	80	6.55	7.80	8.43	8.39
1990 (2 sites)	35	7.29	7.10	7.31	7.44
1991 (3 sites)	76	7.81	8.88	9.73	9.08
Mean	65	7.30	8.06	8.67	8.41

there was additional nitrogen added at planting as the fertilizer P rate increased. Although nitrogen was added as a post plant application to supply all the nitrogen requirements, a portion of the yield response may have been due to the increased N at planting.

5.0 SUMMARY AND RECOMMENDATIONS

The results of this study can be summarized as follows.

1) The strip band fertilizer application system appears slightly superior to the side band. However, the difference is not sufficient to justify the cost of conversion of planters. Therefore it is not appropriate to recommend this method of application.

2) The coulter strip application was not adequately evaluated due to the adverse planting conditions in 1991 and the lack of a response to fertilizer in 1990. However, the position of the fertilizer as indicated by the 1990 sampling suggests that this system does not incorporate the fertilizer to a sufficient depth to provide the desired early P absorption.

3) The cross slot planter appears to be quite promising and is worthy of further evaluation.

4) Current OMAF recommendations for fertilizer P are adequate for conservation tillage systems even when the soil available P value is low.

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APPENDIX TABLES

Table A1

Early shoot growth and nutrient concentration
Huron County 1990

Planter	Placement	P Rate	June 12				June 19				June 27			
			DM	N	P	K	DM	N	P	K	DM	N	P	K
		kg ha^{-1} (P_2O_5)	g pl^{-1}	---	g kg^{-1}---		g pl^{-1}	---	g kg^{-1}---		g pl^{-1}	---	g kg^{-1}---	
Guelph	-	0	0.08	38.4	3.6	23.0	0.29	41.4	3.9	34.3	1.04	40.9	4.3	29.2
	With seed	11	0.09	43.4	4.6	25.1	0.39	43.4	4.3	33.2	1.40	40.0	4.1	25.7
	Side band	11	0.09	39.9	3.7	29.8	0.36	42.4	4.2	36.9	1.29	39.8	4.3	27.9
		22	0.10	39.6	3.6	31.4	0.33	42.8	4.2	37.7	1.23	40.8	4.3	33.4
		44	0.09	39.9	3.7	27.9	0.32	42.6	4.1	38.1	1.23	45.9	4.9	36.7
		88	0.09	40.3	3.9	25.9	0.34	43.5	4.3	38.8	1.39	42.8	5.0	32.6
	Strip band	11	0.09	40.3	3.8	28.7	0.37	41.1	3.7	42.3	1.29	41.0	4.3	33.4
		22	0.10	40.3	3.7	32.9	0.34	42.1	3.9	39.1	1.25	40.8	4.2	34.5
		44	0.09	40.8	3.8	31.8	0.38	42.0	3.9	40.9	1.15	41.3	4.2	36.9
		88	0.09	41.0	3.8	31.6	0.38	43.0	4.3	36.9	1.31	43.3	4.8	30.2
Shillinglaw		0	0.08	40.8	4.3	31.4	0.34	42.3	4.1	37.3	1.18	42.2	4.3	30.9
	Side band	22	0.09	42.3	4.4	35.6	0.35	41.2	4.0	38.0	1.48	42.2	4.5	37.0
		44	0.10	45.0	5.2	37.6	0.44	42.5	4.8	35.0	1.53	44.3	4.8	29.0
	Coulter strip	22	0.08	41.3	4.4	28.0	0.32	43.5	4.5	34.2	1.39	42.8	4.5	30.9
		44	0.08	41.8	4.8	34.8	0.38	43.3	4.7	37.3	1.70	42.3	4.5	36.9
Standard error of means			0.005	0.68	0.16	3.29	0.03	1.06	0.21	2.44	0.10	1.82	0.21	3.15

1/ Planted May 24 , June 12 - 3 leaf stage

June 19 - 4 to 6 leaf stage

June 27 - 7 t0 8 leaf stage

Table A2

Leaf nutrient concentration, percent silking, ear moisture, and final grain yield

Huron County 1990

Planter	Placement	P Rate	Leaf nutrients[1] N	P	K	Silking[2]	Ear moisture	Grain yield
		kg ha^{-1} (P_2O_5)	(g kg^{-1})			%	%	tonne ha^{-1} @ 15.5 % moisture
Guelph	-	0	28.8	2.8	13.7	11	28	6.28
	With seed	11	33.0	2.8	12.7	16	28	5.81
	Side band	11	30.1	2.9	13.7	26	29	6.25
		22	30.8	2.8	14.4	24	29	6.22
		44	30.1	2.9	13.9	18	28	6.59
		88	30.5	2.8	14.6	42	27	6.57
	Strip band	11	29.8	2.9	14.7	29	28	6.40
		22	29.9	2.9	15.8	26	28	6.24
		44	29.9	2.9	15.1	18	28	6.51
		88	30.0	2.9	13.7	32	30	6.18
Shillinglaw		0	37.0	2.9	15.4	36	29	6.49
	Side band	22	31.3	2.8	15.6	56	28	6.97
		44	31.5	2.8	15.9	72	28	7.38
	Coulter strip	22	30.8	2.8	16.1	54	27	7.21
		44	31.5	2.8	15.3	52	28	6.61
Standard error of means			1.21	0.07	1.09	8.4		0.22

[1]/ Mid third of leaf opposite and below ear at 50 % silking

[2]/ % of plants silked on Aug. 7

Table A3

Early shoot growth and nutrient concentration

Oxford County 1990

Placement	P Rate	June 13				June 19				June 26			
		DM	N	P	K	DM	N	P	K	DM	N	P	K
	kg ha^{-1} (P_2O_5)	g pl^{-1}	---	g kg^{-1}---		g pl^{-1}	---	g kg^{-1}---		g pl^{-1}	---	g kg^{-1} ---	
Check	0	0.19	41.2	3.7	44.6	8.81	3.29	3.5	45.3	1.72	39.5	3.5	44.1
With seed	11	0.24	44.1	4.5	45.8	6.73	3.36	3.5	46.9	1.40	40.4	3.5	44.8
Side band	22	0.21	41.9	3.5	44.5	7.11	3.35	3.4	46.5	1.69	39.3	3.4	44.2
	44	0.21	43.3	3.9	45.1	9.37	3.47	4.0	44.5	2.02	39.3	3.8	41.9
	88	0.25	45.2	4.7	43.2	11.12	3.79	4.5	44.4	2.65	39.9	4.2	48.5
	132	0.23	45.5	4.8	43.3	11.46	3.96	4.8	43.5	2.69	42.4	4.5	41.8
Strip band	22	0.23	41.8	3.5	43.4	8.19	3.48	3.7	43.6	1.81	40.7	3.6	42.7
	44	0.21	42.7	3.7	41.2	8.18	3.42	3.9	41.6	1.89	39.8	3.8	41.6
	88	0.22	44.1	4.1	45.0	8.76	3.44	4.0	41.8	1.98	40.1	3.9	42.7
	132	0.24	42.8	4.1	48.2	10.12	3.40	4.1	44.6	2.08	39.9	3.9	45.5
Standard error of means		0.01	0.67	0.18	1.36	0.05	0.80	0.12	2.17	0.12	0.62	0.12	2.38

1/ Planted May 15, June 13 - 4 leaf stage

June 19 - 5 to 7 leaf stage

June 26 - 9 to 10 leaf stage

Table A4

Leaf nutrient concentration, percent silking, ear moisture, and final grain yield

Oxford County 1990

Placement	P Rate	Leaf Nutrients[1]			Silking[2]	Ear Moisture	Grain yield
	kg ha^{-1} (P_2O_5)	N	P (g kg^{-1})	K	%	%	(tonne ha^{-1} @ 15.5 % (moisture)
Check	0	31.9	3.0	21.3	9	32	8.29
With seed	11	31.8	2.9	20.0	14	33	8.20
Side band	22	31.1	2.9	20.1	19	32	7.95
	44	33.2	3.0	18.4	33	32	8.39
	88	32.9	3.0	18.5	48	31	8.29
	132	33.0	3.0	17.8	57	31	8.72
Strip band	22	32.7	3.0	19.5	23	31	8.33
	44	32.2	3.0	19.5	21	33	7.88
	88	32.0	3.0	19.4	28	32	8.26
	132	32.4	3.0	19.8	34	32	8.41
Standard error of means		0.81	0.06	0.79	5.64		0.22

[1]/ Mid - third of leaf opposite and below ear at 50 % silking

[2]/ Percent of plants silked on Aug. 3

Table A5

Early shoot growth and nutrient concentration

Kent County - 1991

Planter	Placement	P Rate	June 3				June 10				June 17			
			DM	N	P	K	DM	N	P	K	DM	N	P	K
		kg ha^{-1} (P_2O_5)	g pl^{-1}	--- g kg^{-1}---			g pl^{-1}	--- g kg^{-1}---			g pl^{-1}	--- g kg^{-1}---		
Guelph	-	0	0.68	36.7	3.6	48.8	1.92	28.2	3.3	42.7	3.94	23.2	3.4	36.4
	Side band with seed	60	1.09	43.6	8.5	45.2	3.79	33.4	6.7	37.9	7.77	28.7	4.7	34.1
	Side band	25	0.98	41.1	5.7	44.5	2.42	27.2	4.1	44.6	5.99	22.2	3.2	37.2
		50	1.24	44.3	7.4	46.8	3.59	31.2	6.0	43.3	7.00	26.5	4.3	35.2
		75	1.37	45.0	7.5	44.5	3.59	30.2	6.0	36.7	7.59	24.7	4.0	32.7
		100	1.25	44.3	7.7	42.4	4.28	32.3	5.8	37.2	8.90	26.4	4.2	31.4
	Strip band	25	0.98	39.9	5.5	47.9	2.51	28.1	4.2	43.2	5.64	22.4	3.3	39.4
		50	0.93	40.8	6.5	50.2	2.54	32.2	5.1	42.3	6.48	23.4	3.6	36.6
		75	1.14	42.3	6.1	41.7	3.36	29.5	4.7	35.4	7.15	22.8	3.5	27.6
		100	1.17	42.2	7.6	45.6	3.11	31.7	6.1	42.6	6.58	26.1	4.4	32.7
Cross - slot	-	0	0.91	38.1	4.1	50.2	2.41	28.8	4.0	43.8	5.43	23.1	3.5	36.7
		50	1.21	42.0	6.3	46.6	3.43	28.2	5.4	46.6	7.21	24.6	4.0	39.1
		100	1.44	44.6	7.3	40.1	3.57	29.6	5.0	42.0	9.72	25.7	4.2	41.5
Rigby	-	0	0.42	40.6	4.0	48.8	1.69	30.5	4.0	47.3	3.98	27.9	3.9	46.4
Standard error of means			0.09	1.23	0.45	2.31	0.25	1.59	0.38	2.71	0.56	0.96	0.22	2.58

[1]/ Planted - Two reps - May 3

- Three reps - May 15

June 3 - First planting - 6 to 7 leaf stage, Second planting - 4 to 5 leaf stage

June 10 - First planting - 7 to 8 leaf stage, Second planting - 6 leaf stage

June 17 - First planting - 8 leaf stage, Second planting 7 leaf stage

Table A6

Leaf nutrient concentration at silking

Kent County - 1991

Planter	Placement	P Rate	N	P	K	Mg	Ca	Mn	Cu	Zn	B
		kg ha^{-1} (P_2O_5)	g kg^{-1}					mg kg^{-1}			
Guelph	-	0	21.8	2.3	15.1	3.3	9.1	28.8	6.8	13.6	5.4
	Side band with seed	60	21.5	2.3	16.5	4.1	12.4	34.4	8.8	9.8	5.8
	Side band	25	23.4	2.3	17.3	3.1	10.5	31.4	7.2	12.0	6.0
		50	23.1	2.3	18.2	3.4	10.8	36.6	7.4	11.2	5.4
		75	23.0	2.3	15.8	3.9	11.7	36.6	6.8	11.0	5.4
		100	21.6	2.3	14.9	4.3	11.2	38.3	8.5	10.0	6.3
	Strip band	25	23.0	2.3	16.7	3.1	9.7	32.8	7.4	12.6	5.4
		50	23.8	2.4	17.6	3.2	9.8	33.8	8.2	12.2	5.8
		75	22.9	2.3	16.2	3.6	10.7	33.5	8.8	12.3	5.5
		100	21.9	2.3	16.5	4.0	11.1	31.6	7.2	11.0	5.4
Cross - slot	-	0	22.2	2.1	17.6	2.7	9.5	28.8	6.6	11.6	5.6
		50	23.8	2.2	18.8	3.1	10.6	28.4	6.6	11.6	5.4
		100	22.9	2.2	18.2	2.9	11.2	32.2	7.0	11.0	6.2
Rigby	-	0	26.5	2.5	17.7	2.7	9.6	38.13	7.9	15.4	6.1
Standard error of means			1.13	0.12	1.38	0.29	0.61	3.4	0.71	1.0	0.39

[1]/ Sampled - July 18 1991

Table A7

Plant emergence, silking percentage, ear moisture, and grain yield

Kent County - 1991

Planter	Placement	P Rate	Plant[1] Emergence	Silking [2]	Ear Moisture	Grain Yield
		kg P_2O_5 ha^{-1}	(%)	(%)	(%)	t ha^{-1} @ 15.5 %
Guelph	-	0	98	28	26	8.60
	Side band/ with seed	60		41	21	8.54
	Side band	25		41	23	8.91
		50		55	21	9.67
		75		54	20	8.62
		100		62	18	8.77
	Strip band	25		36	22	9.41
		50		46	25	9.79
		75		62	21	9.80
		100	97	54	21	9.14
Cross slot		0	56	31	27	8.18
		50		41	24	9.48
		100	77	54	22	8.85
Rigby	-	0	37	13	25	9.05
Standard error of means			9.7	8.3	1.4	0.75

[1]/ % of final plant stand emerged on May 23 for plots planted on May 15

[2]/ % of Plants silked July 18

Table A8

Early shoot growth and nutrient concentration

Huron County - 1991

Planter	Placement	P Rate	June 6				June 14				June 24			
			DM	N	P	K	DM	N	P	K	DM	N	P	K
		kg ha^{-1} (P_2O_5)	g pl^{-1}	--- g kg^{-1}---			g pl^{-1}	--- g kg^{-1}---			g pl^{-1}	--- g kg^{-1}---		
Guelph	-	0	0.20	34.8	3.0	18.1	0.45	39.6	3.3	19.6	2.68	33.4	2.7	17.0
	With seed	10	0.28	34.2	5.2	15.4	0.73	43.9	4.7	16.4	3.90	33.1	3.0	13.8
	Side band	45	0.29	43.6	4.7	19.3	0.74	45.8	5.0	15.7	5.58	34.8	3.6	12.5
	Side band with seed	55	0.30	46.0	5.4	17.5	0.88	44.5	5.4	16.0	5.76	35.5	3.7	11.9
	Side band	90	0.29	44.6	4.8	21.2	0.72	48.1	6.0	15.0	5.90	37.4	4.2	11.6
	Side band with seed	100	0.31	48.0	5.7	17.5	0.75	47.5	6.2	14.3	5.22	36.7	4.4	10.4
	Side band	135	0.32	45.6	5.1	21.3	0.93	48.9	6.1	18.3	6.26	37.2	4.3	12.1
	Side band with seed	145	0.31	49.7	6.5	16.3	0.81	48.9	6.5	14.5	6.18	36.0	4.4	10.4
	Side Band	180	0.29	49.8	5.9	18.1	0.81	50.8	6.8	15.6	5.74	37.4	4.9	10.9
	Side band with seed	190	0.36	48.5	5.9	18.6	0.99	50.4	6.6	15.6	6.20	37.3	4.6	10.5
Cross Slot	-	0	0.20	33.7	2.6	28.2	0.48	40.5	3.6	27.2	2.90	34.0	2.7	23.8
		45	0.23	42.9	4.4	25.8	0.71	43.9	4.9	20.0	6.02	33.9	3.3	20.1
		90	0.27	45.4	5.0	26.3	0.83	45.6	5.1	23.9	6.64	35.5	3.6	14.9
Shillinglaw	-	0	0.19	34.7	2.9	27.8	0.53	41.3	3.8	31.8	3.67	33.8	2.9	25.9
	Side band	45	0.20	36.6	3.1	30.6	0.56	42.6	4.0	39.2	5.56	33.7	3.1	24.6
		90	0.24	37.6	3.9	33.9	0.62	43.1	4.3	35.3	5.18	33.2	3.1	24.3
	Coulter strip	45	0.22	36.3	3.3	27.3	0.61	43.2	4.3	34.4	4.96	33.8	3.1	23.7
		90	0.22	38.1	3.5	30.8	0.69	43.9	4.7	35.1	6.58	33.5	3.3	22.1
Standard error of means			0.02	1.07	0.25	1.70	0.07	0.86	0.21	1.61	0.56	0.67	0.13	1.22

1/ Planted - May 24

June 6 - 3 to 4 leaf stage

June 14 - 4 to 5 leaf stage

June 24 - 6 to 8 leaf stage

Table A9
Leaf nutrient concentration at silking
Huron County - 1991

Planter	Placement	P Rate	N	P	K	Mg	Ca	Mn	Cu	Zn	B
		kg ha^{-1} (P_2O_5)	g kg^{-1}					mg kg^{-1}			
Guelph	-	0	26.4	1.8	10.1	5.4	9.9	24.8	9.2	35.0	5.2
	With seed	10	27.0	1.8	9.2	6.5	11.4	32.2	10.2	36.4	5.2
	Side band	45	28.1	2.2	8.8	8.1	13.4	39.0	11.6	33.2	5.0
	Side band with seed	55	26.7	2.3	8.6	7.4	12.5	34.2	12.0	32.0	5.4
	Side band	90	28.3	2.3	7.7	8.3	13.1	37.2	12.2	28.2	5.2
	Side band with seed	100	28.7	2.6	7.7	8.0	12.8	35.2	12.2	27.0	4.8
	Side band	135	27.3	2.6	8.0	8.3	12.3	50.5	11.5	27.3	5.0
	Side band with seed	145	28.5	2.6	7.9	8.4	13.1	40.0	12.4	27.0	5.2
	Side Band	180	28.1	2.9	7.7	8.9	13.1	41.0	11.0	25.0	5.6
	Side band with seed	190	28.9	3.0	8.1	8.6	13.8	42.8	11.8	24.8	5.2
Cross Slot	-	0	28.5	1.6	10.1	5.7	10.9	26.4	9.2	34.0	5.4
		45	26.5	2.1	8.6	7.7	12.7	30.8	11.0	31.4	5.0
		90	28.9	2.3	8.8	7.6	13.1	36.2	10.6	30.4	4.6
Shillinglaw	-	0	27.5	1.7	10.0	6.0	11.1	25.2	9.3	37.9	5.7
	Side band	45	27.3	1.8	10.6	6.0	11.4	28.6	10.2	41.2	5.4
		90	26.8	1.9	11.1	5.8	11.0	24.8	10.2	39.0	4.8
	Coulter strip	45	27.9	2.0	10.3	6.6	12.2	28.8	9.8	33.4	5.4
		90	27.4	2.1	9.7	7.0	12.2	31.4	10.4	32.4	5.6
Standard error of means			0.66	0.11	0.59	0.33	0.39	2.49	0.45	1.65	0.31

1/ Sampled - July 25 1991

Table A10

Plant emergence, silking percentage, ear moisture, and grain yield

Huron County - 1991

Planter	Placement	P Rate	Plant[1] Emergence	Silking [2]	Ear Moisture	Grain Yield
		kg P_2O_5 ha^{-1}	(%)	(%)	(%)	t ha^{-1} @ 15.5 %
Guelph	-	0	88	15	34	5.62
	With seed	10	79	37	31	5.45
	Side band	45		44	30	7.12
	Side band/ with seed	55		55	31	7.72
	Side band	90		46	30	7.91
	Side band/ with seed	100		38	30	7.61
	Side band	135		62	27	8.42
	Side band/ with seed	145		39	30	7.81
	Side band	180	81	46	29	7.66
	Side band/ with seed	190	98	56	27	8.09
Cross slot		0	60	25	32	6.18
		45		60	29	7.63
		90	60	65	27	8.01
Shillinglaw	-	0	38	40	31	7.16
	Side band	45		70	29	8.13
		90		68	28	8.04
	Coulter strip	45		72	29	8.18
		90		75	27	9.12
Standard error of means			12.1	7.3	1.1	0.5

[1]/ % of final plant stand emerged on May 29

[2]/ % of Plants silked July 25

Table A11

Early shoot growth and nutrient concentration

Oxford County - 1991

Planter	Placement	P Rate	May 31				June 10			
			DM	N	P	K	DM	N	P	K
		kg ha^{-1} (P_2O_5)	g pl^{-1}	------- g kg^{-1}------			g pl^{-1}	------ g kg^{-1}------		
Guelph	-	0	0.57	38.5	3.3	47.3	2.89	37.3	3.1	38.9
	Side band with seed	100	0.94	44.7	5.7	50.2	5.30	36.1	3.7	37.3
	Side band	45	0.93	44.1	5.4	52.2	5.86	37.3	3.4	40.1
		90	0.91	44.8	5.3	48.5	5.67	38.5	4.1	33.4
		135	0.89	46.0	6.3	50.5	5.51	39.0	4.2	35.1
		180	0.99	46.6	6.5	48.9	5.96	39.5	4.7	35.2
	Strip band	45	0.92	42.4	4.4	54.2	5.49	36.6	3.5	43.3
		90	1.04	44.7	5.4	49.6	5.79	38.0	3.7	36.7
		135	1.04	44.6	5.2	45.6	6.41	38.4	3.9	27.5
		180	1.20	44.1	6.0	44.6	6.23	37.1	4.0	34.9
Cross - slot	-	0	0.46	38.4	3.1	50.6	3.32	38.1	3.3	43.8
		45	0.65	42.5	4.2	49.2	3.78	38.3	3.6	41.1
		90	0.71	44.8	4.9	49.0	3.90	38.4	4.0	36.9
Standard error of means			0.08	1.07	0.31	2.53	0.50	0.78	0.13	4.23

1/ Planted May 8 May 31 - 4 to 6 leaf stage

June 10 - 7 to 8 leaf stage

Table A12

Leaf nutrient concentration at silking

Oxford County - 1991

Planter	Placement	P Rate	N	P	K	Mg	Ca	Mn	Cu	Zn	B
		kg ha^{-1} (P_2O_5)	---------- g kg^{-1} ----------					---------- mg kg^{-1} ----------			
Guelph	-	0	27.9	2.0	19.1	3.2	8.0	53.5	13.3	34.7	6.0
	Side band with seed	100	27.7	2.2	17.5	3.3	9.0	71.5	12.0	26.8	6.3
	Side band	45	29.0	2.3	19.7	3.0	9.0	66.8	12.5	30.8	8.5
		90	26.3	2.2	19.0	3.0	8.1	69.3	11.8	24.0	5.8
		135	28.1	2.3	18.0	3.8	9.4	70.3	12.8	25.9	6.8
		180	27.8	2.4	18.7	3.4	9.5	82.3	12.5	20.0	6.5
	Strip band	45	26.1	2.2	19.8	2.7	7.7	63.5	11.8	27.0	6.3
		90	28.0	2.4	18.8	3.5	9.1	66.5	11.8	25.9	6.0
		135	26.8	2.3	17.0	3.9	9.7	75.5	12.5	24.5	6.5
		180	28.4	2.5	18.1	3.6	7.6	77.8	11.5	24.0	6.0
Cross - slot	-	0	27.8	2.1	20.0	2.2	7.1	55.8	12.5	33.0	6.0
		45	26.2	2.0	19.0	2.6	7.4	56.3	11.0	26.8	6.3
		90	28.8	2.2	19.5	2.6	7.7	57.5	13.0	31.1	6.5
Standard error of means			0.98	0.08	1.25	0.35	0.78	5.2	0.84	2.06	0.86

[1]/ Sampled - July 16 1991

Table A13

Silking percentage, ear moisture, and grain yield

Oxford County - 1991

Planter	Placement	P Rate	Silking [1]	Ear Moisture	Grain Yield
		kg P_2O_5 ha^{-1}	(%)	(%)	t ha^{-1} @ 15.5 %
Guelph	-	0	42	32	9.20
	Side band with seed	100	87	28	10.34
	Side band	45	94	28	10.62
		90	93	28	11.61
		135	89	28	10.51
		180	93	27	10.81
	Strip band	45	94	26	11.30
		90	93	28	11.50
		135	95	27	10.92
		180	98	26	10.94
Cross slot	-	0	48	31	9.58
		45	68	30	10.33
		90	74	30	10.61
Standard error of means			7.4	0.84	0.37

[1]/ % of Plants silked July 16

APPENDIX FIGURES

Position of fertilizer bands in relation to the seed as indicated by concentration of available P in soil.

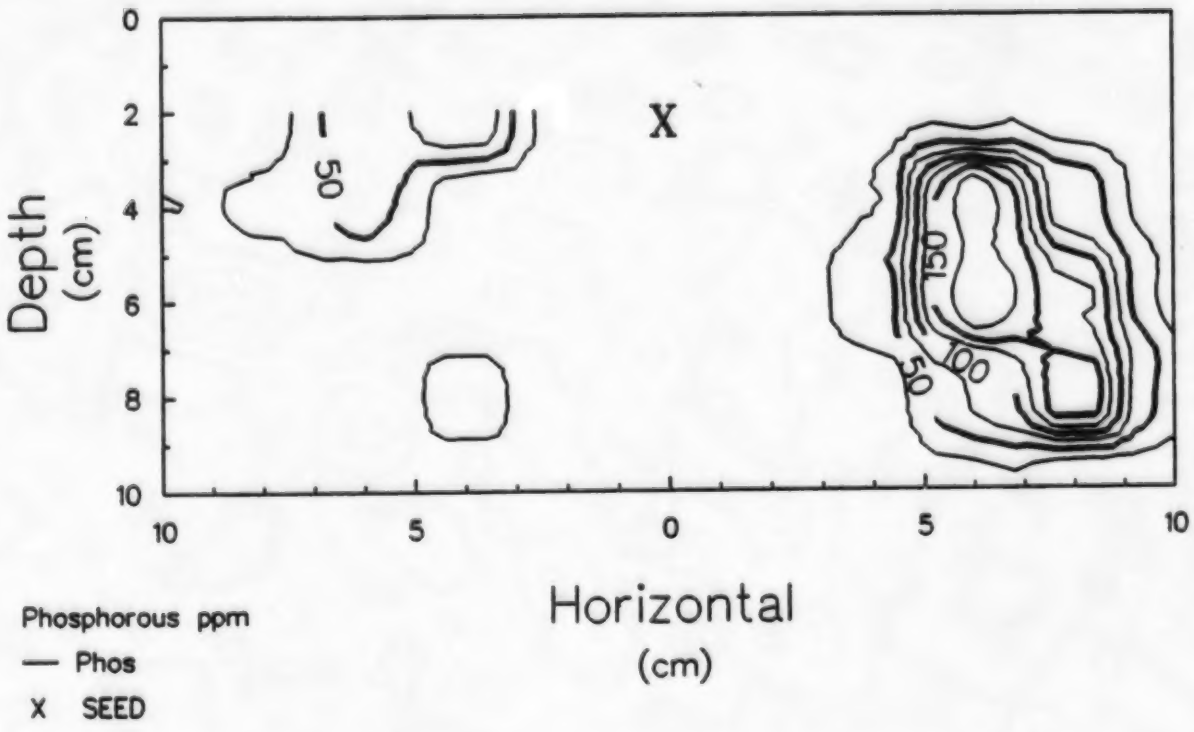

Figure 1: Position of side band with Guelph planter.

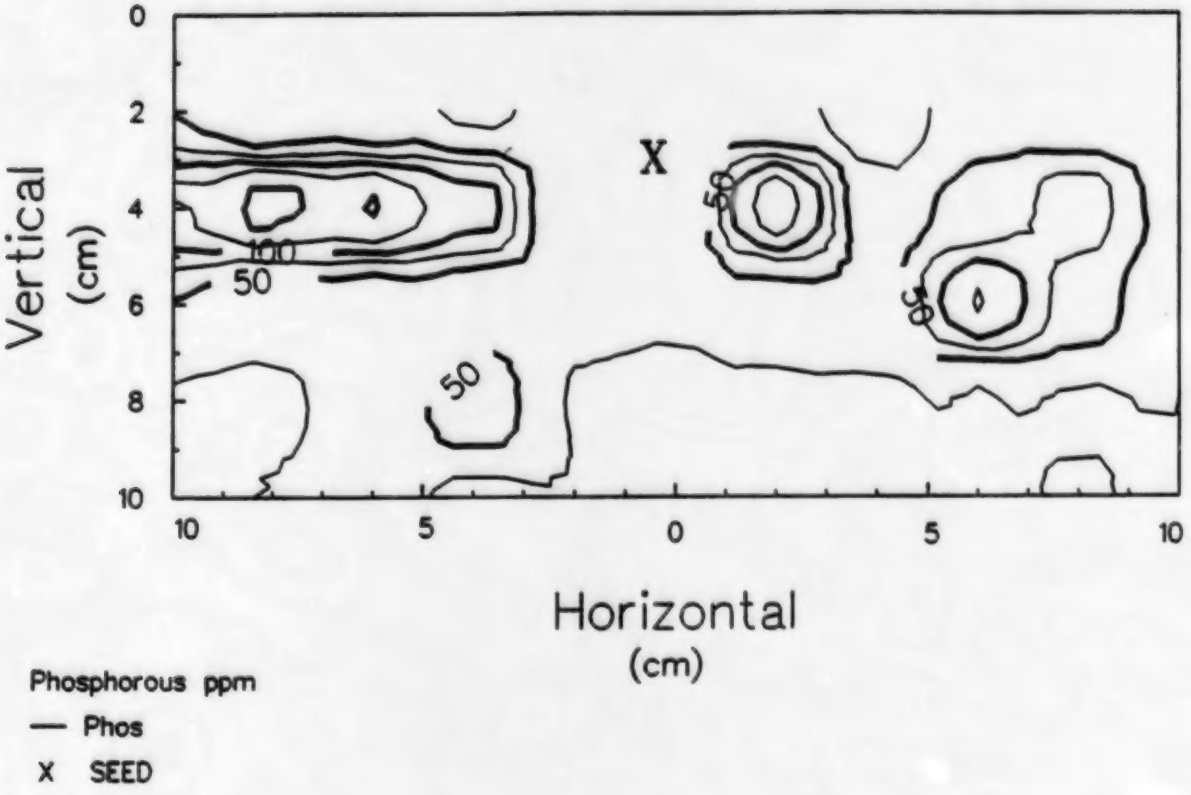

Figure 2: Position of strip band with Guelph planter.

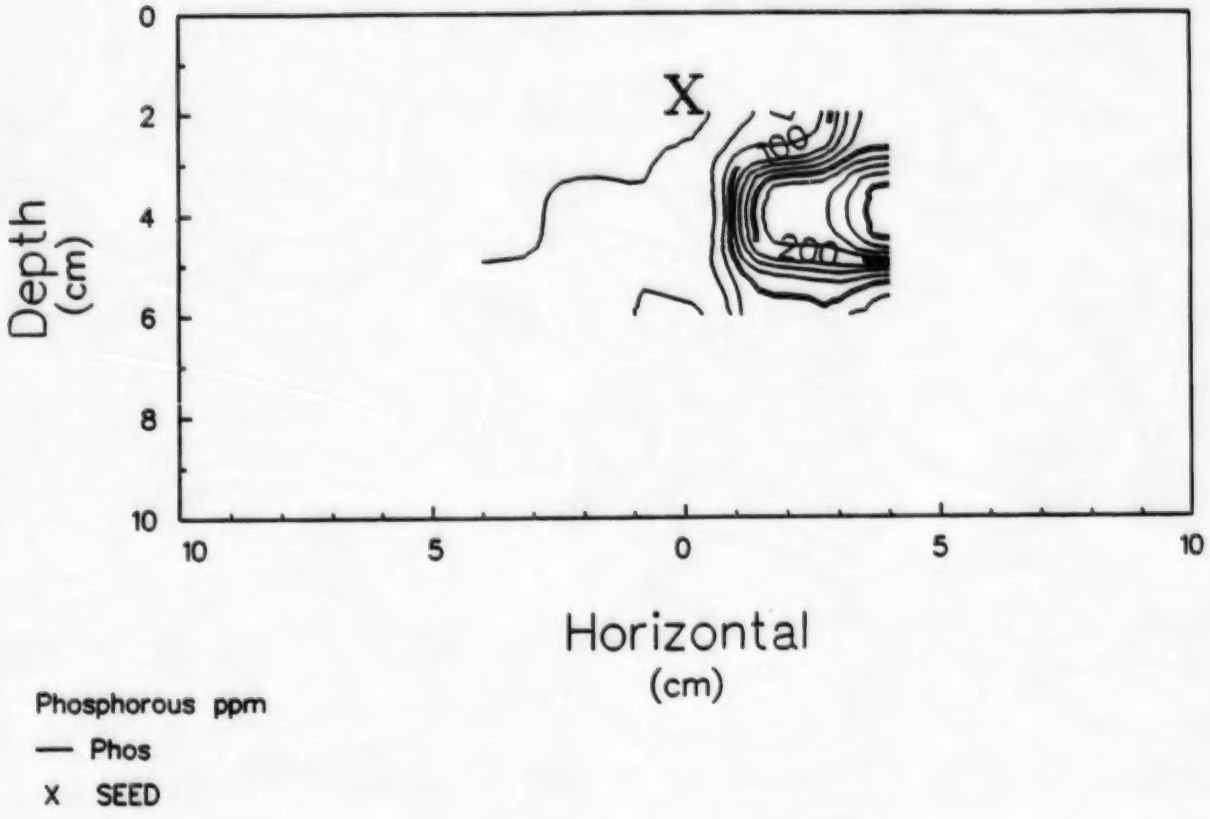

Figure 3. Position of fertilizer band with the cross slot planter.

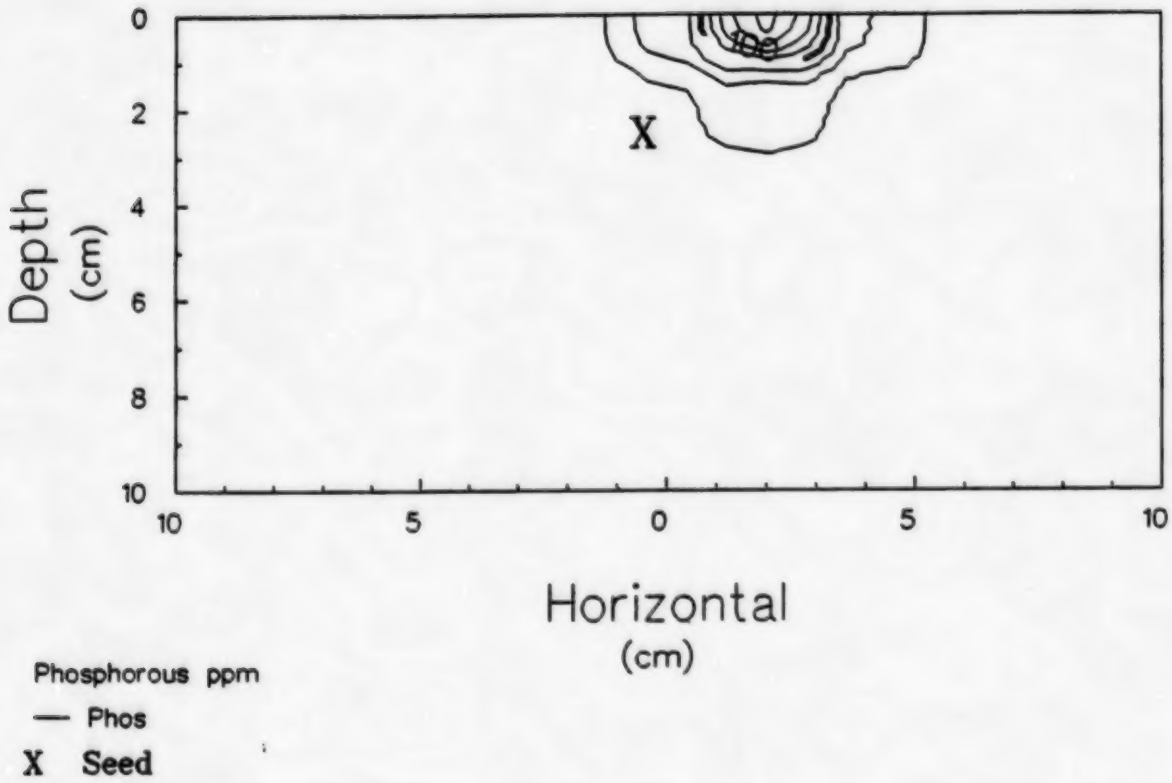

Figure 4. Position of coulter strip band with Shillinglaw planter.